NASA TECHNICAL MEMORANDUM

TM-75349

NASA-TM-75349 19800008747

# THE MECHANISM OF TEMPERATURE AND PRESSURE CHANGES IN THE EARTH'S ATMOSPHERE DURING SOLAR FLARES

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Translation of "O mekhanizme izmenenia temperatury i davlenia v atmosfere zemli pri solnechnykh vspyshkakh," Sun-Atmosphere Relations in Climate Theory and Weather Forecasts; All-Union Conference, 1st, Moscow, USSR, Oct. 30 - Nov. 1, 1972, Transactions, Leningrad, Gidrometeoizdat, 1974, pp. 288-296.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER JUNE, 1979

STANDARD TITLE PAGE

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
| --- | --- | --- |
| NASA TM-75349 | | |

| 4. Title and Subtitle | 5. Report Date |
| --- | --- |
| THE MECHANISM OF TEMPERATURE AND PRESSURE CHANGES IN THE EARTH'S ATMOSPHERE DURING SOLAR FLARES | June 1979 |
| | 6. Performing Organization Code |
| 7. Author(s) | 8. Performing Organization Report No. |
| V. D. Reshetov | 10. Work Unit No. |
| 9. Performing Organization Name and Address | 11. Contract or Grant No. |
| SCITRAN<br>Box 5456<br>Santa Barbara, CA 93108 | NASW-3198 |
| | 13. Type of Report and Period Covered |
| | Translation |
| 12. Sponsoring Agency Name and Address | 14. Sponsoring Agency Code |
| National Aeronautics and Space Administration<br>Washington, D.C. 20546 | |

15. Supplementary Notes

Translation of "O mekhanizme izmenenia temperatury i davlenia v atmosfere zemli pri solnechnykh vspyshkakh," Sun-Atmosphere Relations in Climate Theory and Weather Forecasts; All-Union Conference, 1st, Moscow, USSR, Oct. 30 - Nov. 1, 1972, Transactions, Leningrad, Gidrometeoizdat, 1974, pp. 288-296.

16. Abstract

The article examines the effect of solar flares on the weather on Earth. It concludes that the processes which arise in the atmosphere are so intricate that a single calculation of solar activity is insufficient for long-range forecasting. But combined consideration of processes dependent upon the dynamic instability of the atmosphere and the effect of solar activity will contribute to the improvement of long-range forecasts.

| 17. Key Words (Selected by Author(s)) | 18. Distribution Statement |
| --- | --- |
| | Unclassified - Unlimited |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. |
| --- | --- | --- | --- |
| Unclassified | Unclassified | 14 | |

# THE MECHANISM OF TEMPERATURE AND PRESSURE CHANGES IN THE EARTH'S ATMOSPHERE DURING SOLAR FLARES

V. D. Reshetov

We know that an additional stream of intense radiation is directed towards the Earth during the passage of sunspots near the center of the solar disk. We are apparently observing a solar flare. A part of the solar flare's corpuscular radiation is trapped by the Earth's magnetic field and concentrated where the lines of magnetic force converge -- near the magnetic poles (73°N, 100°W and 68°S, 140°E). /1*

The work of G.A. Kokin (5), Y.P. Koshel'kov and D.A. Tarasenko (6), Ivanov-Kholodny, T.V. Kazachevskaya, G.A. Kokin, V.V. Mikhnevich (3), B.M. Rubashev (11), V.I. Bekoryukov and V.S. Purgansky (1) has established that during magnetic storms there is a warming of the upper atmosphere in the polar regions which increases with altitude.

It is also known that the majority of magnetic storms are observed one or two days following the onset of solar activity and are caused by corpuscular radiation from the Sun penetrating the atmosphere.

We shall examine the nature of temperature changes in the upper atmosphere during the passage of sunspots across the solar disk through one specific example. On 27 September 1969 from approximately 2AM to 4AM (GMT) a large group of extremely intense sunspots with an area of around 130 millionths of the Sun's visible surface traversed the central solar meridian at 7°N (solar latitude). The effects of the energy associated with this solar flare can be seen on the map of thermosphere temperatures at 260km altitude on 27 and 28 September 1969 published by Blamont and Luton (14) (fig. 1).

It is apparent that on 28 September 1969 the areas of greatest heating at 260km were those near the magnetic poles (air temperature here was 1300 -- 1400°K, and in other regions 1000---1200°K).

*Numbers in margin indicate foreign pagination.

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In fig. 1a we can see that there are widespread temperature field and circulation disturbances in the thermosphere as well as in lower atmosphere layers. In this example, two temperature waves predominate, extending roughly from west to east with wavelengths of about 180 degrees of longitude. We can also see that two long pressure waves predominated on the Earth's surface this day (fig. 1c). Areas of increased pressure on the Earth's surface (fig. 1c) coincide with regions of increased temperature in the thermosphere (fig. 1a), while areas of decreased temperature in the thermosphere coincide with regions of decreased pressure on the surface of the Earth.

Such correspondence is not strict, however, but is observed only in most zones of the global thermobaric field.

The map we have compiled (fig. 1b) according to the data from (14) shows that between 27 and 28 September 1969 the thermosphere at the North Magnetic Pole was heated by 400°K, and at the South Magnetic Pole by 200°K. At the same time it can distinctly be seen that at the lower latitudes of the Northern Hemisphere and in part of the Southern Hemisphere the temperature of the thermosphere decreased by 50 -- 100°K.

According to fig. 2 the atmospheric heating in the polar regions by the solar flare (27 -- 28 September 1969) spread downward to an altitude of approximately 10km, but in the area from 10 to 25 or 35km it amounted to only a few dozen degrees. It diminished rather quickly at the transition from the thermosphere to the mesosphere and stratosphere, and did not penetrate the troposphere. Throughout the lower latitudes there was an appreciable temperature decrease, averaging 50°K at an altitude of 260km and falling to 0.5°K up to an altitude of 10km in the equatorial regions. A general cooling enveloped the thermosphere.

In areas of greatest heating and cooling, maximum temperatures occurring in certain areas near the meridian which passes through the magnetic poles are also shown in fig. 2, beneath the underlining. The picture of temperature changes presented in this figure is clearly that of half a temperature wave enveloping the entire globe from pole to pole.

Arrows indicate the vertical motions causing this temperature wave. In areas of maximum heating at high latitudes and cooling at low latitudes (averaging +150 and -50°K over a twenty-four-hour period) vertical velocities at about 260km altitude amounted to, respectively, -4 m/s (descending motion) and +2 m/s (ascending motion). Calculations show that, in order to provide this much vertical motion, the velocity of converging winds in the thermosphere must reach several dozen meters per second. Kolkin's experimental data confirms the initiation of high winds in the upper atmosphere during solar flares (5).

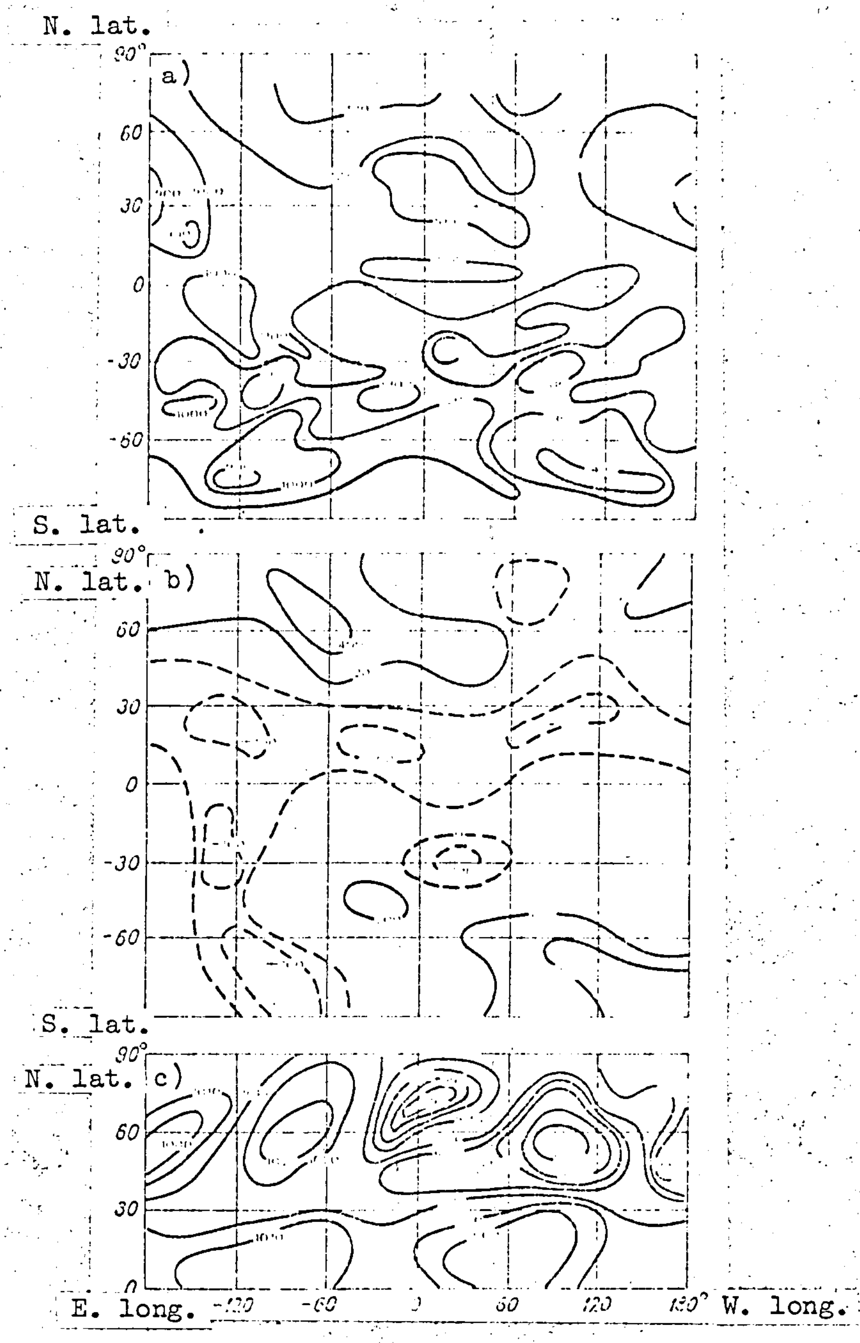


Fig. 1. Thermobaric field at 260 km altitude and on the Earth's surface during solar flare.

a) distribution of temperatures at 260 km, 28 September 1969, according to the data of (14); b) temperature changes at 260km from 27 to 28 September 1969 during solar flare; c) distribution of pressures on the Earth's surface 28 September 1969.

We can see from fig. 1b that the temperature wave oriented along circles of latitude is accompanied by a temperature wave aligned with the meridians. In both the Northern and Southern Hemispheres the greatest

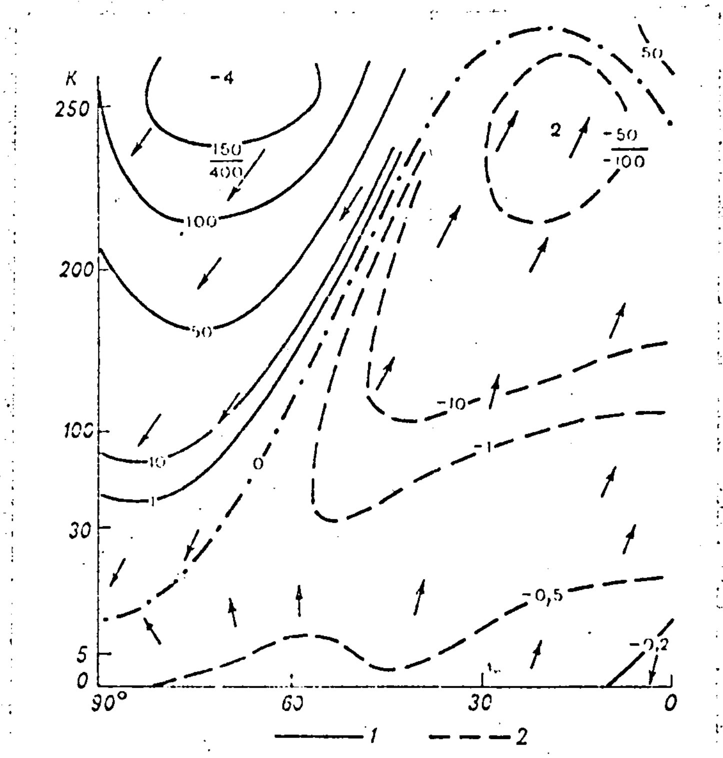


Fig. 2. Atmospheric temperature changes one day after solar flare, with diagram of vertical motions.

1 -- lines of equal heating, 2 -- lines of equal cooling of the air for the 24-hour period, by circle of latitude.

air heating at 260km altitude is detected near those meridians on which the magnetic poles are located (100°W and 140°E), and the greatest cooling near meridians whose longitudes lie approximately 180° from those passing through the magnetic poles. Therefore, as a result of corpuscular radiation from solar spots striking the upper atmosphere in the regions of the magnetic poles for a one to two day period, a system of two world-wide standing temperature waves was formed. One

of them had its greatest temperature increase near the magnetic poles, and its greatest temperature decrease in the tropic zone. The other temperature wave was oriented along meridians, with the maximum temperatures near meridians on which the magnetic poles are located 15
and the minimums near meridians differing from the previous ones by $\pm$ 180° (fig. 1). Obviously, the second wave would not exist if the magnetic poles coincided with the geographical poles. The increase in temperature around the magnetic poles was caused primarily by the energy of corpuscular radiation from the solar flare. But, since regions of cooling are found distributed symmetrically by both circles of latitude and meridians, this indicates that, along with the initial warming of the upper atmosphere in the magnetic polar regions, there was a simultaneous initiation of descending motion in the atmosphere of these regions. There was a compensatory ascending motion in the lower latitudes and near meridians differing by approximately 180° from those of the magnetic poles at latitudes greater than 45° in both hemispheres.

The vertical velocities cited in fig. 2 (−4 m/s descending at higher latitudes and +2 m/s ascending at lower latitudes) were calculated without regard to heat flow, using the equation

$$\frac{\partial T}{\partial t} = -(\gamma_a - \gamma) w. \qquad (1)$$

Vertical velocity as an effect of bouyancy force in a heterogeneous heavy liquid (gas) can be estimated using the relationship we obtained from (12):

$$w = -A \frac{\Delta \rho}{\rho}, \qquad (2)$$

where $\rho$ should be interpreted as the average density in the layer $H$, $\Delta\rho$ as its Laplacian, and $A = \frac{\varepsilon g k H^2}{l^2}$. In the last expression,

$\underline{g}$ is the acceleration due to gravity, $\underline{k}$ is the coefficient of friction, $\underline{l}$ is the Coriolis factor, and $\varepsilon$ is an empirically determined dimensionless factor less than unity.

With the aid of Clapeyron's equation and a barometrical formulas the density Laplacian in the layer can be expressed (with some simplifying assumptions) as

$$\frac{\Delta \rho}{\rho} = \left(\frac{HT_0}{2H_0T_m} - 1\right)\frac{\Delta T_m}{T_m}, \qquad (3)$$

where H is the thickness of the layer having the temperature Laplacian $\Delta T_m$, $H_0$ is the altitude of the homogeneous atmosphere, and $T_m$ is the average temperature of the layer ($T_0 = 273$).

From relationships (3) and (2) we can see that if the region of increased temperature covers a depth of less than 16 to 20km in the troposphere and stratosphere, or less than 50 to 60km in the thermosphere, the air in these layers must on average be lighter and, as is usual, /6
"surface" under the influence of buoyancy force. If even a slight warming pervades the entire thickness, the increased pressure in the upper layers leads to such an increase in density that descending motion develops.

Using (2) and (3), equation (1) may be rewritten as

$$\frac{\partial T_m}{\partial t} = B\,\Delta T_m,$$

where

$$B = \frac{(\gamma_a - \gamma)\,\varepsilon g k H^2}{l^2 T_m}\left(\frac{HT_0}{2H_0T_m}\right). \qquad (4)$$

In the region of temperature changes, $T_m$ does not have a particularly wide range of values, while $\underline{B}$ may be considered something of a constant; therefore, for a limited segment of time, assuming

$$\Delta T = \frac{\partial^2 T}{\partial \xi^2} + \frac{\partial^2 T}{\partial \eta^2},$$

we arrive at the following particular equation:

$$\delta T = \delta T_1 \sum^{j,\, i} e^{B(j^2+i^2)t} \left[\cos j(\varphi - \varphi_n) + \cos i(\lambda - \lambda_n)\right]; \tag{5}$$

$$j = 1,\ 2,\ 3,\ \ldots;\quad i = 1,\ 2,\ 3,\ \ldots$$

In this expression the value $\delta T_1$ represents initial warming by the solar flare. This warming, as can be seen from equation (5), may be extremely small, but it builds up exponentially and has an "explosive" nature.

Equation (5) basically describes the previously mentioned system of standing temperature waves arising in the thermosphere during solar flares.

The equation shows that the upper atmosphere tends toward large scale autoconvection and acts as a kind of amplifier for the disturbing forces, if they are aligned in space.

We can see that limited heating of the thermosphere by energy from the solar flare's corpuscular radiation leads to the development of vertical motion, and also causes a considerable temperature increase in the higher latitudes and decrease in the lower latitudes. The energy for generating the temperature waves decribed above is derived from this temperature difference (5).

A diagram of the most powerful waves caused by solar activity is shown in fig. 3a. They correspond to wave numbers j = i = 1 in equation (5). The second most powerful system of such waves, with wave numbers j = i = 2, is depicted in fig. 3b. There may be waves with even higher wave numbers, depending on the condition of the atmosphere. What these waves have in common is that their main peaks are located in the regions of the magnetic poles, as a consequence of which the remaining elements of the system have fixed positions. The wave diagrams shown in fig. 3 coincide well with the surface pressure wave diagrams statistically compiled from the experiments of E.R. Mustel' (7),

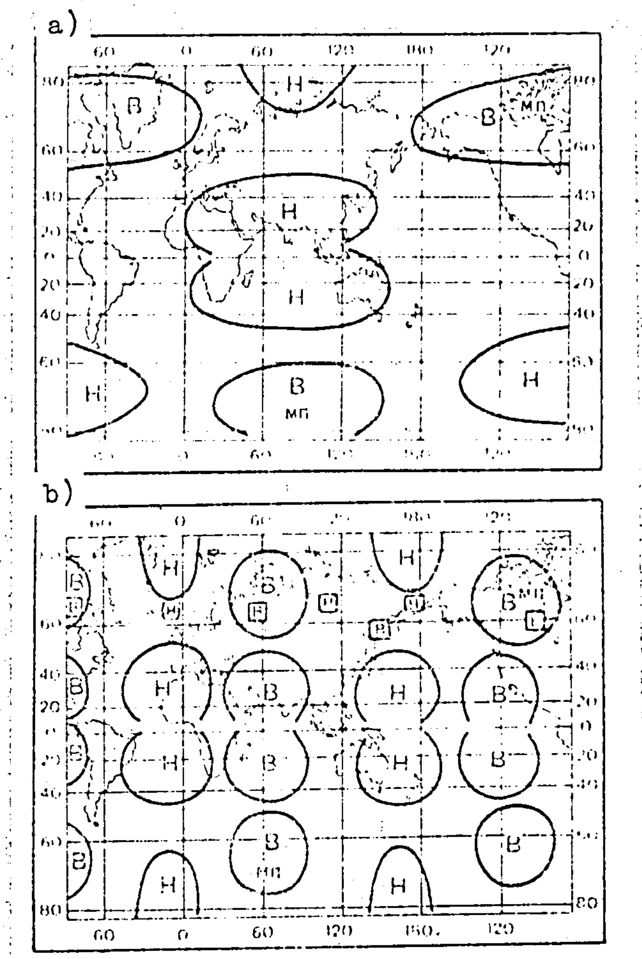


Fig. 3. Diagram of standing temperature waves in the upper atmosphere and pressure on the Earth's surface surface caused by increased solar activity.

a -- first wave system (j = 1, i = 1);
b -- second wave system (j = 2, i = 2).

T.V. Pokrovskaya (9), A.V. D'yakov (2), V. Mironovitch (15), E.E Fedorov (12), and G.T. Walker (16). For comparison, the distribution of centers of increased and decreased pressure during solar flares, from

Mustel', are shown in fig. 3b by small squares.

The diagrams in fig. 3 are to some extent prognostic. At times of intensified solar activity standing waves of the type shown in fig. 3 tend to occur. They form a kind of massive background circulation. General synoptic knowledge and the relationship of cyclonic and anticyclonic circulation to the weather, as set forth in the monographs of S.P. Khromov (13), S.T. Pagava (8), A.L. Kats (4), and others permit us to predict prevailing weather patterns in various geographical regions when solar activity appears. As we can see (fig. 3), the wave system produced by solar activity leads to the prevalence of an anticyclogenic northeastern flow in the European USSR. It is recognized that this condition results in a hot, dry summer and a cold winter with little snowfall. In south-central Siberia and Altai it portends a summer of cold, damp cyclonic weather. The forecasting methods of T.V. Pokrovskaya (9) and A.V. D'yakov (2) are based on evaluation of such conditions. Since solar activity is a regularly recurring phenomenon, its influence is a factor in the formulation of climatic weather standards. It follows that during abatement of solar activity we can expect weather anomalies contrasting with those observed during intensified solar activity. /8

The circulation processes that arise spontaneously in the atmosphere are so intricate and intense that a single calculation of solar activity is insufficient for long-range forecasting. But combined consideration of processes dependent upon the dynamic instability of the atmosphere, the effect of solar activity, and other factors will unquestionably contribute to the improvement of long-range forecasts.

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